

Postoperative Pulmonary Function in Symptomatic Neonates with Congenital Lung Malformations: A Retrospective Cohort Study

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Research Article

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Abstract

Background

Pulmonary function after elective resection has been reported in asymptomatic infants and older children; however, evidence regarding early postoperative lung function in symptomatic neonates requiring urgent surgery remains scarce. We characterized the early postoperative pulmonary function in symptomatic neonates with congenital lung malformations (CLMs) requiring urgent surgery, and explored whether disproportionate airway parenchymal growth (dysanapsis) may underlie the observed functional limitations.

Methods

This retrospective cohort study included children with CLMs who underwent surgical resection, categorized into a neonatal urgent surgery group—comprising symptomatic infants with respiratory distress—and an elective reference group—comprising asymptomatic infants undergoing scheduled resection. Postoperative pulmonary function was assessed within 6 months post-surgery using tidal breathing flow volume loop (TBFV) technology. The primary inferential analysis focused on factors associated with moderate to severe obstructive dysfunction within the neonatal subgroup.

Results

Abnormal postoperative pulmonary function was present in all neonates in the neonatal urgent surgery group, compared with 64.2% in the elective reference group ($p < 0.001$). Obstructive ventilatory dysfunction predominated in both groups and was more common among neonates ($p = 0.033$). Moderate to severe obstruction (time to peak tidal expiratory flow as a proportion of expiratory time $< 23\%$) was also more frequent in neonates (57.9% vs. 22.6%, $p = 0.002$). Within the neonatal subgroup, exploratory multivariable analysis identified lobectomy, preoperative invasive mechanical ventilation), and prenatal maximum congenital pulmonary airway malformation volume ratio > 1.6 as factors associated with more severe dysfunction.

Conclusions

Symptomatic neonates requiring urgent CLM resection have a uniformly high incidence of early postoperative pulmonary dysfunction, predominantly obstructive. Notably, the pattern of preserved tidal volume but reduced expiratory flow ratios is consistent with dysanapsis—a disproportionate growth of airways relative to lung parenchyma. These findings support structured respiratory follow up and highlight the need for research on long term airway development after neonatal CLM surgery.

1. Background

Congenital lung malformations (CLMs) are a heterogeneous group of developmental anomalies involving the fetal lung parenchyma, airways, and pulmonary vasculature, and include congenital pulmonary airway malformation (CPAM), bronchopulmonary sequestration (BPS), congenital lobar overinflation, bronchogenic cyst, and related hybrid lesions [1]. Improved prenatal ultrasonography and fetal magnetic resonance imaging (MRI) have increased antenatal detection, and contemporary literature suggests that CLMs are more common than previously recognized, with overall prevalence estimates of approximately 3.7–4.0 per 10,000 live births and CPAM incidence approaching 1 in 7,200 births in some screened populations [2–4].

Despite this rising detection rate, most fetuses and newborns with CLMs remain asymptomatic, and fewer than 10% develop respiratory symptoms immediately after birth [1, 5]. Management of asymptomatic lesions remains controversial, with no international consensus on the ideal balance between elective resection and conservative surveillance [5, 6]. By contrast, there is a broad agreement that symptomatic lesions causing respiratory compromise require urgent intervention. These symptomatic neonates constitute a clinically distinct and much higher risk subgroup whose outcomes cannot be inferred from elective infant cohorts.

Prenatal risk stratification is therefore central to counseling and perinatal planning. Ultrasonography remains the first line imaging modality, whereas fetal MRI provides complementary anatomic and volumetric information, particularly in complex lesions [3]. Among available prenatal markers, the CPAM volume ratio (CVR) remains one of the most widely used prognostic indicators; $CVR > 1.6$, mediastinal shift, and fetal hydrops are consistently associated with more severe perinatal disease and need for intensive management [3, 7]. However, prenatal phenotyping is imperfect. Recent research has shown that although antenatal detection rates are high, the specific prenatal diagnosis often differs from the final postnatal diagnosis, especially in hybrid lesions [4].

Although pulmonary function after elective resection has been reported in asymptomatic infants and older children, evidence regarding early postoperative lung function in symptomatic neonates requiring urgent surgery remains scarce [8–11]. Moreover, a key observation in many pediatric surgical cohorts is that some children achieve near normal lung volumes on imaging but nevertheless exhibit persistent airflow limitation that cannot be fully explained by residual anatomical defects or surgical complications. This phenomenon raises the possibility of disproportionate growth between the airways and the lung parenchyma—a concept termed dysanapsis [12, 13].

Dysanapsis was first described by Green et al. [12] to explain interindividual variability in maximum expiratory flow relative to lung size, and later extended by Mead [13] as a mismatch between airway caliber and lung volume. Importantly, dysanapsis is now recognized as a determinant of lung function in both development and disease [14]. It has been observed in preterm born individuals [15, 16], children with obesity related asthma [17], and survivors of early life respiratory insults. However, whether

neonatal lung resection for CLM may alter the normal coordinated growth of airways and parenchyma, leading to a dysanaptic pattern, remains unexplored.

Accordingly, the present study was designed not merely as a clinical outcome assessment but as an investigation into the pattern of lung development after CLM resection. Our primary aims were to: (1) characterize the early postoperative pulmonary function phenotype of symptomatic neonates with CLM requiring urgent surgery, and (2) identify prenatal and perioperative factors associated with worse dysfunction. We further aimed to interpret our findings in the context of dysanapsis, generating the hypothesis that neonatal lung resection may alter airway-parenchymal growth trajectories.

2. Methods

2.1 Study Subjects

This retrospective observational study was approved by the Ethics Committee of the Capital Center for Children's Health (No. DWLL2019005). Informed consent was waived owing to the retrospective design. We reviewed the electronic medical records of all pediatric patients prenatally diagnosed with CPAM or BPS who underwent surgical resection at the Department of Neonatal Surgery of our institution between January 2018 and January 2025.

Inclusion criteria were: (1) prenatal diagnosis of CPAM or BPS confirmed postnatally by chest CT and surgical pathology; (2) completion of postoperative pulmonary function testing and chest CT within 6 months after surgery; and (3) availability of complete clinical records. Exclusion criteria were: (1) other severe congenital anomalies, such as congenital diaphragmatic hernia, complex congenital heart disease, or chromosomal abnormalities; (2) bilateral lung lesions; and (3) loss to follow up or incomplete pulmonary function data.

Patients were grouped according to the clinical context in which surgery was performed. The neonatal urgent surgery group comprised infants who underwent surgery within 28 days of birth because of respiratory distress, defined as respiratory rate > 60 breaths/min and transcutaneous oxygen saturation < 90% on room air despite initial medical management. All patients in this group were symptomatic at birth. The elective reference group comprised asymptomatic infants who underwent scheduled surgery at 3–6 months of age according to our institutional policy for prenatally diagnosed CLMs without symptoms.

Importantly, these groups represent two clinically distinct populations—symptomatic life-saving intervention versus asymptomatic prophylactic resection—rather than a randomized or severity matched comparison of surgical timing. Therefore, between group analyses were interpreted descriptively and used only to contextualize the burden of dysfunction in the neonatal group. The primary inferential analysis was restricted to the neonatal subgroup. (Fig. 1)

2.2 Study Methods

2.2.1 Data Collection

Clinical variables were extracted from the medical records and categorized as follows:

1. Prenatal indicators: maximum prenatal CVR, calculated as $(\text{length} \times \text{width} \times \text{height} \times 0.523) / \text{fetal head circumference}$; mediastinal shift (deviation from midline > 5 mm); and fetal hydrops (presence of at least two of the following: skin edema ≥ 5 mm, pericardial effusion, ascites, or pleural effusion).
2. Surgical indicators: surgical approach (thoracoscopy vs. open thoracotomy), extent of resection (lobectomy, segmentectomy, or irregular/wedge resection), and pathological diagnosis (CPAM or BPS).
3. Perioperative indicators: preoperative respiratory support (nasal cannula, noninvasive ventilation, or invasive mechanical ventilation), preoperative pulmonary infection, postoperative air leak, and duration of postoperative invasive ventilation.

2.2.2 Pulmonary Function Tests

Postoperative pulmonary function was assessed within 6 months after surgery using tidal breathing flow volume loop (TBFV) technology (MasterScreen BabyBody Plethysmograph, Jaeger, Germany). TBFV is a recommended and widely used method for evaluating respiratory function in infants and young children who cannot perform reliable forced expiratory maneuvers [12, 13]. The methodological rationale for using infant tidal breathing parameters rather than spirometric indices is also supported by the 2024 Chinese expert consensus on pediatric lung function testing—which specifically recommends age-appropriate approaches such as TBFV for low age (under 3 years old) children [14].

All examinations were performed by an experienced technician after oral chloral hydrate sedation (0.5 mL/kg) with the infant in the supine position and using a tightly fitting face mask without air leakage. Fifteen to twenty consecutive tidal breaths were recorded. The analyzed parameters included tidal volume per kilogram (VT/kg), time to peak tidal expiratory flow as a proportion of expiratory time (TPTEF/TE), volume to peak expiratory flow as a proportion of exhaled volume (VPEF/VE), and inspiratory to expiratory time ratio (TI/TE).

Abnormal pulmonary function was defined as $\text{VT/kg} < 6$ mL/kg (restrictive pattern) and/or $\text{TPTEF/TE} < 28\%$ (obstructive pattern). Obstructive dysfunction was classified as mild (TPTEF/TE 23–27%), moderate (15–22%), or severe ($< 15\%$). As TBFV captures an early life functional phenotype rather than school-age spirometric performance, these measurements were interpreted as markers of early postoperative respiratory recovery, not as definitive long term pulmonary endpoints.

2.2.3 Statistical Methods

SPSS 26.0 statistical software was used for data analysis. Continuous variables are presented as mean $\pm$ standard deviation or median (interquartile range), as appropriate, and were compared using Student's t-test or the Mann–Whitney U test. Categorical variables are presented as number (percentage) and were

compared using the chi-square test or Fisher's exact test. For the primary exploratory analysis, univariate and multivariable logistic regression models were constructed within the neonatal urgent surgery subgroup to identify factors associated with moderate-to-severe obstructive dysfunction (TPTEF/TE < 23%). Variables with $p < 0.10$ in univariate analysis were considered for multivariable modeling. Given the small size of the neonatal subgroup ($n = 19$), the number of covariates was deliberately limited to reduce overfitting, and the resulting estimates were interpreted as exploratory. Odds ratios (ORs) with 95% confidence intervals (CIs) were reported. A two-sided $p < 0.05$ was considered statistically significant.

3. Results

3.1 Study Cohort and Baseline Characteristics

A total of 158 patients were initially screened. After exclusion of 12 children with other severe congenital anomalies, 8 with bilateral lesions, and 13 with incomplete follow up or pulmonary function data, 125 patients were included in the final analysis: 19 in the neonatal urgent surgery group and 106 in the elective reference group (Table 1).

Table 1
Baseline and clinical characteristics of the study population

Variable	Neonatal urgent-surgery group (n = 19)	Elective reference group (n = 106)	p-value
Male, n (%)	11 (57.9)	59 (55.7)	0.855
Gestational age at birth, weeks	37.4 ± 2.1	38.2 ± 1.6	0.112
Birth weight, kg	3.02 ± 0.51	3.15 ± 0.48	0.293
Prenatal maximum CVR	2.04 ± 0.67	0.91 ± 0.42	< 0.001
Mediastinal shift, n (%)	15 (78.9)	25 (23.6)	< 0.001
Fetal hydrops, n (%)	6 (31.6)	3 (2.8)	< 0.001
Preoperative invasive mechanical ventilation, n (%)	11 (57.9)	0 (0)	< 0.001
Age at surgery, days	14.2 ± 8.5	142 ± 31	< 0.001
Thoracoscopic approach, n (%)	12 (63.2)	94 (88.7)	0.009
Lobectomy, n (%)	14 (73.7)	41 (38.7)	0.005
Segmentectomy/irregular resection, n (%)	5 (26.3)	65 (61.3)	0.005
Pathological diagnosis (CPAM), n (%)	16 (84.2)	91 (85.8)	0.856
CVR, CPAM volume ratio; CPAM, congenital pulmonary airway malformation.			

As expected, the neonatal urgent surgery group differed significantly from the elective reference group in several markers of disease severity. Neonates had a higher maximum prenatal CVR, more frequent mediastinal shift and fetal hydrops, a substantially greater need for preoperative invasive mechanical ventilation, and a higher frequency of lobectomy.

3.2 Early Postoperative Pulmonary Function Phenotype

Pulmonary function testing was performed at a median age of 6.2 months (IQR 5.5–7.0) in the neonatal urgent surgery group and 9.5 months (IQR 8.5–10.5) in the elective reference group ($p < 0.001$), reflecting both differences in age at surgery and the standardized postoperative follow up window (Table 2).

Table 2
Early postoperative pulmonary function outcomes

Variable	Neonatal urgent-surgery group (n = 19)	Elective reference group (n = 106)	p-value
Abnormal pulmonary function, n (%)	19 (100)	68 (64.2)	< 0.001
Obstructive pattern, n (%)	16 (84.2)	64 (94.1)	0.033
Mild obstruction (TPTEF/TE 23–27%), n (%)	5 (31.3)	40 (62.5)	0.342
Moderate-to-severe obstruction (TPTEF/TE < 23%), n (%)	11 (68.7)	24 (37.5)	0.002
Restrictive pattern (VT/kg < 6 mL/kg), n (%)	1 (5.3)	4 (5.9)	0.002
Mixed pattern, n (%)	2 (10.5)	0 (0)	0.026
TPTEF/TE, %, mean ± SD	21.4 ± 6.2	31.5 ± 7.8	< 0.001
VT/kg, mL/kg, mean ± SD	5.8 ± 1.2	7.6 ± 1.5	< 0.001
TI/TE, mean ± SD	0.71 ± 0.12	0.74 ± 0.10	0.247
TPTEF/TE, time to peak tidal expiratory flow as a proportion of expiratory time; VT/kg, tidal volume per kilogram; TI/TE, inspiratory time to expiratory time ratio.			

All 19 neonates in the urgent surgery group had abnormal pulmonary function within 6 months after surgery, whereas 68/106 (64.2%) of the elective reference group had abnormal findings. Obstructive dysfunction was the predominant pattern in both groups but was more frequent and more severe among neonates. Restrictive and mixed patterns were uncommon but occurred almost exclusively in the neonatal group. Taken together, these findings indicate that symptomatic neonates requiring urgent resection exhibit a distinctive early postoperative pulmonary function phenotype characterized primarily by obstructive ventilatory dysfunction.

3.3 Postoperative Lung Volume Assessment

As a physiological surrogate of lung volume, VT/kg was measured in all participants. In the neonatal urgent surgery group, mean VT/kg was 5.8 ± 1.2 mL/kg, which is only mildly reduced compared with the normal reference range (6–10 mL/kg) and was not significantly different from the lower bound of normal ($p = 0.08$ vs. 6 mL/kg). In contrast, the elective reference group had a mean VT/kg of 7.6 ± 1.5 mL/kg, which was within the normal range. Notably, despite the preserved or near preserved VT/kg in neonates, their TPTEF/TE was markedly reduced ($21.4 \pm 6.2\%$ vs. $31.5 \pm 7.8\%$ in the elective group, $p < 0.001$), indicating that the ability to generate expiratory flow was disproportionately impaired relative to the achieved lung volume. These findings suggest that after urgent neonatal resection, the remaining lung

parenchyma can expand to achieve near normal tidal volumes, but this compensatory increase in lung volume is not accompanied by proportional improvement in expiratory airflow—a pattern consistent with dysanapsis.

3.4 Exploratory Risk Factors Within the Neonatal Subgroup

Within the neonatal urgent surgery group, univariate analysis identified lobectomy, preoperative invasive mechanical ventilation, and prenatal maximum CVR > 1.6 as candidate factors associated with moderate to severe obstructive dysfunction (TPTEF/TE < 23%). In the exploratory multivariable model, all three remained associated with more severe dysfunction after limited adjustment, whereas thoracoscopic versus open approach was not significantly associated with severity in this small cohort (Table 3).

Table 3
Exploratory multivariable analysis of factors associated with moderate-to-severe obstructive dysfunction in the neonatal urgent surgery group (n = 19)

Variable	Adjusted OR	95% CI	p-value
Lobectomy (vs. segmentectomy/irregular resection)	4.12	1.23–13.78	0.022
Preoperative invasive mechanical ventilation (yes vs. no)	3.76	1.19–11.85	0.024
Prenatal maximum CVR > 1.6 (yes vs. no)	3.24	1.05–10.02	0.041
CVR, CPAM volume ratio; CPAM, congenital pulmonary airway malformation; OR, odds ratio; CI, confidence interval			

4. Discussion

This study characterized the early postoperative pulmonary function phenotype of symptomatic neonates with CLM requiring urgent surgery and identified prenatal and perioperative factors associated with worse dysfunction. Symptomatic neonates requiring urgent CLM resection differed markedly from asymptomatic infants undergoing elective surgery in all major markers of severity. The central finding that nearly all symptomatic neonates exhibited obstructive dysfunction, often with preserved tidal volumes but reduced expiratory flow ratios (low TPTEF/TE) points to a specific physiological pattern. The present study should be interpreted as a description of disease severity and early postoperative phenotype in a high-risk clinical subgroup, with a novel focus on the pattern of lung function impairment rather than merely its prevalence.

4.1 Dysanapsis as a Unifying Concept

A key observation in our data is that many neonates in the urgent surgery group had a TPTEF/TE < 23% while their tidal volume per kilogram remained within or near the normal range (mean 5.8 ± 1.2 ml/kg). This combination of preserved lung volume but reduced expiratory flow is reminiscent of dysanapsis the disproportionate scaling of airway dimensions to lung parenchyma [12–14]. In the context of CLM, after surgical resection, the remaining lung tissue undergoes compensatory expansion. Alveolar multiplication

and compensatory lung growth have been well documented following lung resection in both animal models and humans [18–20]. However, compensatory enlargement of lung parenchyma may not necessarily be accompanied by proportional development of the conducting airways. The airway tree, once established during fetal and early postnatal life, has limited capacity for additional branching or increases in caliber after the critical developmental window [21].

Thus, even if the remaining lung parenchyma expands to fill the thoracic cavity leading to normalized lung volumes on imaging the airway caliber may remain relatively smaller than expected for the new lung volume. This discordant growth results in expiratory flow limitation, similar to our observation of a low TPTEF/TE. This interpretation is consistent with previous reports of dysanapsis in preterm infants [15, 16] and in children with early-life lung injury [22].

4.2 Evidence for Preserved Lung Volume After Neonatal Resection

Compensatory lung growth after pulmonary resection has been extensively documented in both animal models and humans [18–20]. Following lobectomy, the remaining lung tissue expands to fill the thoracic cavity, largely through alveolar distension and, to a variable extent, true alveolar multiplication [23]. Our finding that mean VT/kg in the neonatal group was 5.8 mL/kg only slightly below the normal range supports the notion that these infants achieved a physiologically adequate lung volume by 6 months after surgery. This is consistent with the findings of previous CT based volumetric studies revealing that residual lobes increase in volume after lobectomy [20]. However, the critical observation is that this volume recovery was not accompanied by normalization of expiratory flow. The persistently low TPTEF/TE indicates that airway function lags behind parenchymal expansion. Such a dissociation is the hallmark of dysanapsis [12–14]. This suggests that while the alveoli and distal airspaces may respond to the mechanical and growth signals induced by resection, the conducting airways whose branching pattern and cartilage structure are largely determined early in development [21] have a limited capacity for catch up growth. Therefore, even when lung volume returns to near normal levels, the airway caliber may remain relatively smaller, leading to expiratory flow limitation. Future studies should directly quantify postoperative lung volumes using CT based volumetry and, where possible, assess airway dimensions using imaging or oscillometry to confirm this dysanaptic relationship.

4.3 Reason for Predisposition of Neonatal Surgery to Dysanapsis

The neonatal period represents a critical developmental window for both airway branching (which is largely complete by birth but continues to mature postnatally) and alveolarization (which continues into early childhood). In our cohort, neonates who underwent lobectomy within the first 28 days of life had a significantly higher risk of moderate to severe obstruction compared to infants operated at 3–6 months. We propose a cautious, hypothesis-generating mechanism: early lung resection may alter the normal postnatal trajectory of airway-parenchymal coordination [23].

This “dual-hit” model (prenatal compression from the malformation, followed by postnatal compensatory expansion after resection) has been previously proposed for other neonatal lung conditions [24] (Fig. 2). Although our study cannot directly prove causality, the pattern of functional impairment is fully consistent with dysanapsis.

4.4 Relationship to Previous Literature

Our findings align with previous reports demonstrating a lower dysanapsis ratio in adults born preterm and identifying a “dysanaptic” spirometry phenotype in preterm born children [15, 22]. In the broader field of pediatric lung surgery, it has been recognized that lobectomy for congenital lung lesions does not completely normalize pulmonary function in all patients [25, 26], and subtle airflow limitation can persist despite good clinical recovery. Our study extends these observations by specifically linking the timing of surgery (neonatal vs. infant) to the severity of obstructive dysfunction, and invoking dysanapsis as a plausible mechanistic explanation.

4.5 Factors Associated with Worse Dysfunction

The three exploratory risk markers identified in the neonatal subgroup-lobectomy, preoperative invasive mechanical ventilation, and prenatal CVR > 1.6 are best understood as severity linked indicators. Lobectomy removes a greater amount of lung parenchyma than segmentectomy, potentially imposing a greater demand for compensatory growth and a higher risk of airway-parenchymal mismatch. Preoperative mechanical ventilation reflects severe respiratory failure and likely contributes to ventilator-induced lung injury, which may further impair airway development. A high CVR indicates a large lesion burden and has long been associated with pulmonary hypoplasia. Notably, these factors are also known to influence dysanaptic growth in other settings [14, 17].

4.6 Clinical Implications and Future Directions

Our findings have several practical implications. First, clinicians should be aware that symptomatic neonates who undergo urgent CLM resection may achieve good clinical recovery but still have measurable airflow limitation. Second, structured longitudinal follow-up with serial lung function testing is warranted, as early dysanapsis may track into later childhood and adulthood [27, 28]. Third, lung sparing resection (segmentectomy rather than lobectomy) should be considered whenever technically feasible and oncologically safe, as it may reduce the degree of airway-parenchymal mismatch.

Future research should focus on: (1) prospective longitudinal studies using age-appropriate spirometry (including forced expiratory maneuvers when children reach school age) to determine whether the obstructive pattern resolves, persists, or progresses; (2) advanced imaging (e.g., CT-based airway morphometry) to directly assess airway caliber relative to lung volume; and (3) mechanistic studies in animal models or human organoids [29] to explore how neonatal lung resection affects airway growth signaling pathways (e.g., Wnt, Fibroblast Growth Factor (FGF), and Hedgehog-interacting protein (HHIP) pathways known to be involved in dysanapsis genetics [30]).

4.7 Study Limitations

Some limitations should be acknowledged. The most important is the non-comparable nature of the two groups; between group differences cannot be interpreted as causal effects of earlier surgery. Additionally, the neonatal subgroup was small, and the risk factor model was exploratory. Next, infant TBFV does not replace later spirometry. Further, we lacked serial follow up beyond infancy, preventing assessment of recovery trajectories. Finally, this was a single center retrospective study. Nevertheless, the consistency of our findings with the concept of dysanapsis supports the plausibility of our hypothesis.

5. Conclusions

Symptomatic neonates with congenital lung malformations who require urgent surgery show a uniformly high rate of early postoperative pulmonary dysfunction, predominantly obstructive. The pattern of preserved lung volume with reduced expiratory flow ratios is consistent with dysanapsis disproportionate growth of airways relative to lung parenchyma. These findings support structured long term respiratory follow up and further research into the developmental origins of airflow limitation after early life lung surgery.

Abbreviations

The following abbreviations are used in this manuscript:

CLMs	Congenital lung malformations
TBFV	Tidal breathing flow volume loop
TPTEF/TE	Time to peak tidal expiratory flow as a proportion of expiratory time
CPAM	Congenital pulmonary airway malformation
CVR	CPAM volume ratio
BPS	Bronchopulmonary sequestration
VPEF/VE	Volume to peak expiratory flow as a proportion of exhaled volume
VT/kg	Tidal volume per kilogram
ORs	Odds ratios
CIs	Confidence intervals
FGF	Fibroblast Growth Factor

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Capital Center for Children's Health (Approval No.: DWLL2019005; Date of approval: December 11, 2025). The need for obtaining informed consent was waived owing to the retrospective design.

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and/or analyzed during this study are not publicly available due to ethical restrictions and patient confidentiality, but may be available from the corresponding author upon reasonable request and with institutional approval.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Chao Liu: Writing—original draft; conceptualization; data curation; investigation; formal analysis; methodology. Ying Wang: Data curation; investigation; resources. Wei Zhang: Data curation; investigation. Lishuang Ma: Writing—review & editing; supervision; conceptualization; funding acquisition.

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Figures

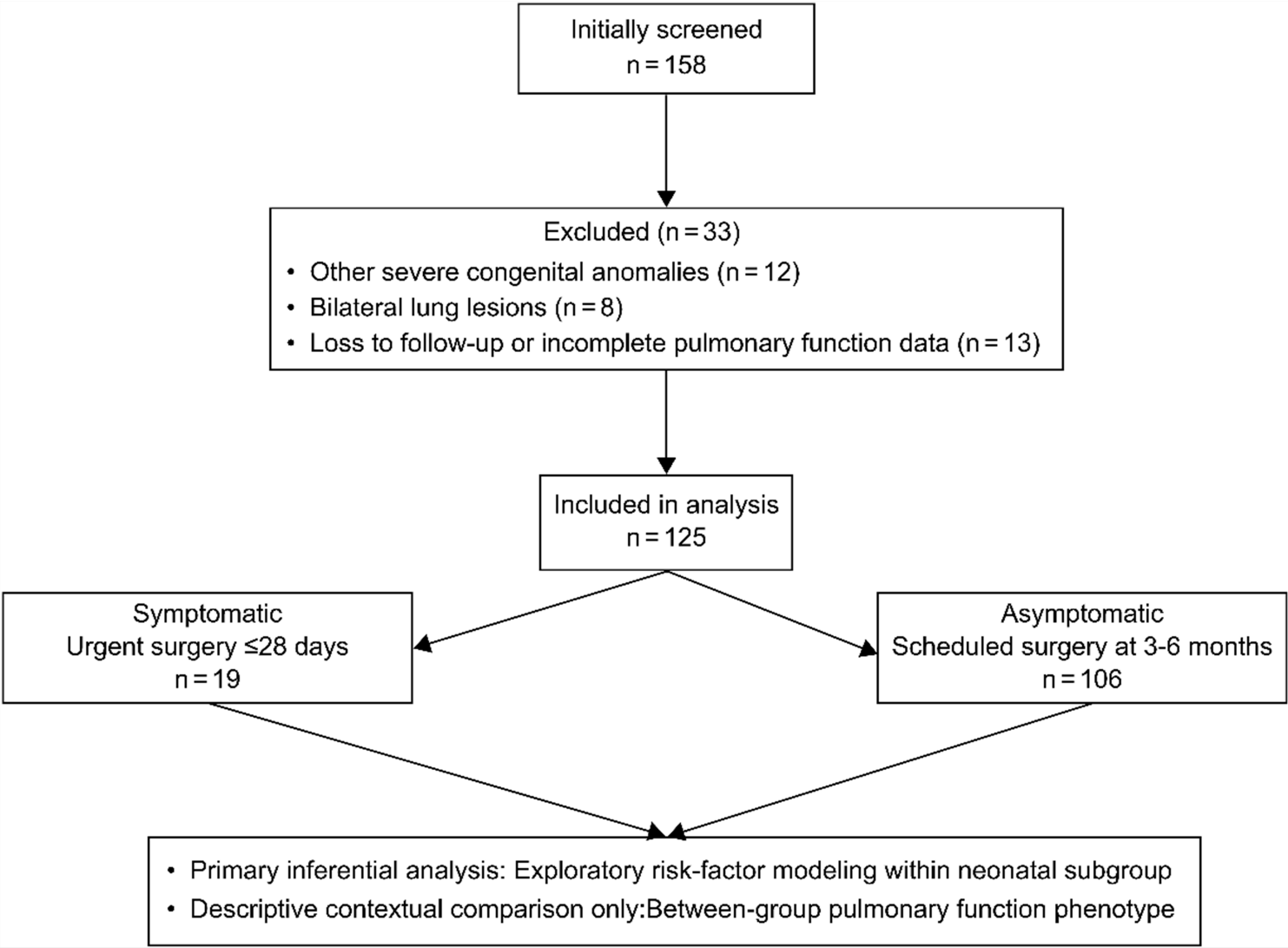


Figure 1

Study cohort and analytic framework

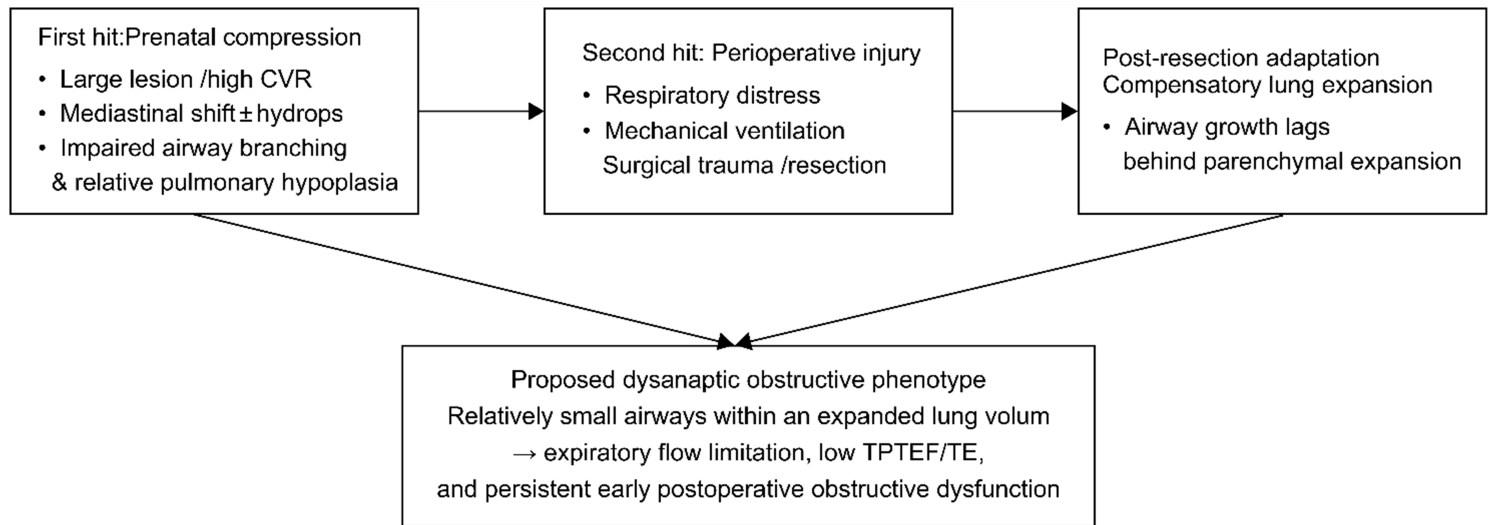


Figure 2

Proposed dual-hit dysanapsis model for early postoperative obstructive dysfunction in symptomatic neonatal CLM. CVR, CPAM volume ratio; CPAM, congenital pulmonary airway malformation; TPTEF/TE, time to peak tidal expiratory flow as a proportion of expiratory time.